DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 27

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION

1. A PRELIMINARY STUDY OF CONDITIONS IN SPRINGFIELD, OHIO, WITH RECOMMENDATIONS FOR MITIGATION

BY

E. B. ROSA, Chief Physicist

and

BURTON McCOLLUM, Associate Physicist

Bureau of Standards

[JUNE 19, 1913]

WASHINGTON
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1914

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PREFACE.

The accompanying report on the electrolysis situation in the city of Springfield, Ohio, has been prepared in the course of a general investigation of the subject of electrolysis from stray earth currents which is being carried out by the Bureau of Standards. In connection with this investigation an examination of conditions in Springfield was made and in the prosecution of this work the Bureau had the cooperation of the Springfield Railway Co., the City Water Department, and the Springfield Gas Co.

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION:

I. A PRELIMINARY STUDY OF CONDITIONS IN SPRINGFIELD, OHIO, WITH RECOMMENDATIONS FOR MITIGATION

By E. B. Rosa and Burton McCollum

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INTRODUCTION

The investigation by the Bureau of Standards into the electrolysis situation in the city of Springfield, Ohio, was undertaken primarily because it afforded an opportunity for making a study of the effec-

tiveness of the insulated negative feeder system at present installed by the Springfield Railway Co. as a means of mitigating damage to pipes and other buried structures by stray currents from the street railway. For this reason the experimental investigation was of a somewhat restricted character, only such data being taken as had a direct bearing on the influence of the negative copper feeders as now installed. For this purpose several series of measurements were made, including potential differences between pipes and rails and potential gradients along the rails from which current densities in the rails could be determined, and also the distribution of current between the different rails which also gave information in regard to the condition of the rail joints. The current flow in the taps connecting the insulated feeders and the rails was also measured; current flow in pipes was determined at a number of points, and over-all potential measurements between a number of points scattered over the city were also taken. These different series of measurements were taken first with the insulated feeders connected to rails in accordance with the plan adopted by the Springfield Railway Co., and then these feeders were temporarily removed, all connections being made the same as they had been prior to the installation of the present feeder system and the same series of measurements was repeated. A comparison of the data of the two series gives an indication of the extent to which the installation of the present feeder system has influenced electrolysis conditions. While these measurements showed that the system as now installed has greatly improved electrolysis conditions, it was found that a number of changes could be made in the system which would improve its operation, both from the standpoint of cost and also its effectiveness as a protection against electrolysis. Such additional information was therefore obtained from the railway company in regard to their traffic and physical condition of plant as was necessary to determine what changes should be made in the feeder system in order to insure adequate protection at a reasonable cost.

A study of the conditions at present existing in the negative return systems in Springfield shows that a readjustment of the insulated negative feeders, together with other changes as indicated later, will give considerably better voltage conditions in

the negative return throughout the city, and at the same time prove considerably more economical to the railway company. In the first place the over-all potential measurements between remote points in the city were found to fluctuate between rather wide limits, due primarily to the high resistance in the negative feeders. It is evident that the potential between any two points of connection of the feeders to the rails will be equal to the difference in the total voltage drops on the two feeders between points of connection on the track and the bus bar. Further, since owing to the constantly shifting character of the load, the current in the separate feeders will necessarily vary considerably, it follows that the actual variation in potential drop of the feeders will also vary, and this variation will be larger the higher the resistance of the feeder, and consequently the difference of potential between points of connection of the feeders to the track will be correspondingly high. If the size of the feeders were increased and the total drops thus reduced, a given percentage variation in the load would produce much less difference of potential between points of attachment of the feeders to the tracks, and such a change would therefore bring about considerable improvement in voltage conditions throughout the city. It will be shown later that this reduction in the total drop of potential on the feeders can be accomplished, however, without increasing the annual cost of the system, but that on the contrary, a considerable saving can be secured.

Another condition of importance in the present system is revealed by the potential drops taken on short lengths of rails in various parts of the city. A great many of these measurements were taken and it was found that the current distribution in the different rails at any one point was often very unequal. This showed that some rail joints were not in good condition, thus giving rise to a relatively high resistance of the track with consequent larger potential gradients than would occur if the rail joints were maintained in better condition. However, conditions in this respect can not be considered as particularly bad. It may further be pointed out that the present negative feeder system is so designed that the current returns to the power house by a much

more indirect route than is necessary or desirable. It was found in fact that not only was all of the current from the central part of the city returned over negative feeders, but that there was a general flow of current from the entire eastern part of the city west as far as Limestone Street, whereas in a properly designed system all of the current from the eastern part of the city should be intercepted at about Sycamore Street, and the tracks farther westward utilized for carrying a moderate amount of current toward the power house instead of away from it, as is now the case. This change would not only improve potential conditions, but it would afford a considerably cheaper installation to the railway company. Means for accomplishing this result are set forth in detail later.

Another defect in the present system grows out of the fact that the rails of the Springfield Railway Co. and of the Ohio Electric Co. are not properly connected at crossings. As a result of this the current can not divide between the various rails in such a manner as to utilize the maximum conductivity of the track and local potential differences are therefore made considerably higher than would otherwise be the case. A proper interconnection of the rails of the two companies with the consequent interchange of current on the negative side would be of great value to both companies from the standpoint of electrolysis protection and also of operating cost. It was further found that the continuity of the rails of the Ohio Electric Co. was very unsatisfactory, a large part of their current being returned through the city as far as Isabella and North Streets by way of the Springfield Railway Co.'s tracks. This, we understand, is a temporary condition due to reconstruction work now going on, and with the completion of this work will disappear.

In the following report we give a very brief general discussion of the various possible methods of electrolysis mitigation, setting forth which methods we consider best adapted in general for reducing electrolysis troubles. This is followed by a somewhat detailed discussion of conditions in Springfield, with recommendations in regard to a permanent system of electrolysis mitigation applicable thereto.

PART I. METHODS OF ELECTROLYSIS MITIGATION

In the effort to reduce or eliminate damage to pipe systems and other subsurface structures due to stray earth currents from street railways, a great many methods have been proposed and tried. Some of these have been widely used with more or less benefit in many instances and apparent failure in others. In the case of most of these but little systematic effort has been made to develop them to meet the requirements of practical service in the most advantageous manner. We present below a very brief discussion of the different methods of electrolysis mitigation that have been proposed, together with our conclusions as to their relative merits. The majority of these methods are either of no value or of such limited application that it has not been deemed worth while to discuss them in any detail, and they have therefore been passed by with merely a brief statement as to their limitations. A few of those methods which have special merit as methods of electrolysis mitigation in general or in special cases are treated at somewhat greater length. We have not attemped to discuss in great detail, however, even these latter methods, since all methods of electrolysis mitigation are discussed at some length in a publication that will shortly be issued by the Bureau of Standards.

Methods of electrolysis mitigation are here treated under two heads: First, those that may be applied to the pipe system for protection of the pipes without regard to the extent of stray current leaking from the rails; second, those which are applied directly to the negative return of the street railways system and have for their object the prevention of the leakage of electric current into the earth or the reduction of such leakage to so low a value as to do practically no harm.

A. METHODS APPLICABLE TO PIPES

1. SURFACE INSULATION OF PIPES

Painting or otherwise insulating the surface of pipes, as by the use of treated papers and textiles, was early resorted to as a possible means of protecting pipes from electrolysis, and this method is still used in some instances. It is doubtful, however, whether

there exists any instance in which it has been definitely proved that insulating paints have effectively protected pipes from electrolysis for any considerable period of time, while there are many instances where they have failed utterly and where their presence has actually done harm. This statement may seem somewhat surprising to some who are familiar with instances where paints have withstood the action of soils for a long period and when uncovered both paint and pipes appeared to be in practically as good condition as when they were laid down. Practically all paints are classed as insulators and it is quite natural that the impression should be more or less prevalent that these paints ought to prove effective as a protection against self-corrosion in the soil. In practice, however, such paints behave in a very uncertain manner at best. A given paint may endure for a long period in some places, while in other places in the same city it may deteriorate rapidly and become worthless in a comparatively short time. This is due partly, no doubt, to differences in soil conditions, but the general failure of these paints under conditions where electrolysis was to be expected indicate that the stray currents themselves have much to do with the destruction of the coatings. With a view of throwing further light on this point and also of determining if possible something of the relative value of different coatings as a possible protection against electrolysis, the Bureau of Standards has undertaken a series of experiments, which, while as yet uncompleted, have yielded considerable definite information. In all about 40 different kinds of paints have been tested and of these not a single one has withstood the action of the very moderate test voltage of 4 volts for any considerable length of time, failure of the coating with consequent pitting of the pipe occuring within a few months in all cases. The explanation of the failure lies in the fact that none of the paints tested are absolutely impervious to moisture, and when brought into the presence of water a slight trace of moisture ultimately permeates the coating. When this occurs at any point the coating becomes slightly conducting, and if an electromotive force is applied, a trace of current flows at first, giving rise to slight electrolysis which is accompanied by the formation of more or less gas beneath the coating. As this gas increases in

amount and expands, the coating is ruptured, after which the current flow is greatly increased at the point of breakdown and rapid electrolysis of the exposed iron follows. In some cases, if the coating is sufficiently porous to permit the gases to escape, it may remain intact and electrolysis may continue beneath the coating, eating through the metal without any superficial evidence of failure of the paint. This phenomenon is frequently observed in practice. The vital weakness of all the paints thus far tested is due to the fact that none of them are entirely nonabsorbent. If a paint could be secured which is absolutely impervious to soil moisture and which would remain so for an indefinite period, it would prove an effective preventive of electrolysis, and all efforts to produce such a protective paint should be directed to this one point of making it absolutely and permanently moisture proof.

The manner in which these paints usually fail under electric stress shows that they may under certain circumstances increase the trouble from electrolysis. Breaking down as they do at isolated points, the discharge of current from the pipes is concentrated at those points and the pitting is likely to be more serious than if the paint were not used at all. In all areas, therefore, where the pipes are strongly positive to the earth, these paints are likely to do more harm than good, and it would be better to omit them altogether. But in places where the pipes are practically neutral, or negative to earth, they can do no harm even if they do fail in spots, and in such places they may be of value in reducing current flow in pipes and in preventing soil corrosion.

The method of coating pipes with treated textiles or tarred paper is open to the same objections that have been given to the use of insulating paints, the only difference being that the time required for their initial failure is usually somewhat greater than in the case of paint. The principal reason for this is the greater thickness of the coating that usually results from this method of insulation. We have tested a considerable number of such coatings with uniformly disappointing results. Among these may be mentioned the coating consisting of four alternate layers of tar and paper as now applied by the Laclede Gas Co. of St. Louis to all their services. A number of samples of this coating have been tested by us under a pressure of 4 volts, as in the case of the paints mentioned above.

A number of pipes coated in this way were buried in damp soil, their ends having been carefully plugged to prevent contact between the metal and the soil. A rubber-covered wire was soldered to each pipe and brought to the surface. When first laid the application of a difference of potential of 4 volts between the pipe and the ground gave no indication of current, thus showing that the coating was continuous and free from flaws. Current readings taken from time to time showed when the coating failed, and it was found that within a few weeks the coatings had been punctured in many places. After about two months some of the specimens were removed for examination and it was found that characteristic blisters had appeared in spots, and beneath these faults serious pitting of the pipes had occurred. The rate at which this pitting progressed indicated that the life of the pipes would not have exceeded a year under the conditions imposed, and it can not be said that these conditions were severe, since a difference of potential of 4 volts between pipes and ground may often be exceeded under practical conditions. The result of the tests of this coating is in line with those made on a great many similar coatings during the past two years, in which the surface coatings have uniformly failed locally, giving rise to severe pitting of the pipes. Where no electromotive force is impressed on the pipes provided with this tar and paper coating it appears to remain in good condition for several years and for this reason it appears to be of at least temporary value as a preventive of self-corrosion. Its use is probably justified in neutral or negative areas, but in all positive areas it would tend to aggravate rather than reduce the rate of deterioration of the pipes. Its use is not, therefore, to be recommended except in neutral or negative areas where it would undoubtedly be beneficial, the only question being whether or not it is worth the cost. As a means of preventing or even reducing electrolytic damage in positive areas this method of surface insulation does not appear to be practicable at the present time.

2. INSULATING JOINTS IN PIPES

Another method of reducing current flow in pipes and one which has found rather extensive application within the last few years is that of breaking up the continuity of the pipe lines by

the use of insulating or resistance joints. In ordinary wrought iron or steel mains with screwed or riveted joints the resistance of the joints is usually small in comparison with that of the pipes, and when such pipes are laid in localities where there is an appreciable potential gradient in the direction of the pipe currents of considerable magnitude will usually be carried by the pipes. In the case of cast-iron mains the resistance of the joint is often as great or greater than that of a section of pipe and it is not uncommon to find a lead joint having a resistance equal to that of several hundred feet or more of pipe, and it is due largely to this high joint resistance and to some extent also to the higher specific resistance of cast iron that cast-iron mains usually carry less current under similar conditions than wrought iron or steel mains. Experience has shown, however, that the resistance of lead joints is not sufficient to reduce the current to a safe value, and attempts have been made to still further increase the resistance of the pipes by the introduction of specially designed joints of high resistance.

Following the earlier attempts to prevent electrolysis by this method very strong claims were made for it by some of its advocates, some of them claiming that they had completely solved the problem of electrolysis by means of insulating joints. Within a few years, however, a noticeable reaction set in; many engineers criticized the method, and some of those who were its warmest advocates in the beginning, abandoned it. It is but natural however, that the initial attempts to apply this method should have resulted in some disappointments, and it is not safe to consider these early failures too seriously in judging the value of the method when properly applied. At that time no experience had been gained in regard to the frequency with which such joints should be used, the proper location of the joints, the kind of joints best suited to certain conditions, and the complications arising from the presence of other pipe systems not so insulated. All of these are important factors and must be carefully considered if adequate protection is to be secured. Despite the criticism it has received in some quarters, the method has, in recent years, steadily gained in favor, and is more frequently encountered at the present time than ever before.

We can not here go into detail in regard to the merits of this method, or the proper procedure in applying it, as this will be fully treated in another publication of this Bureau, and it is sufficient to state here some of the conclusions at which we have arrived as a result of our investigation of this method. If properly installed, with joints of proper construction and used with sufficient frequency, it can be made very effective in minimizing electrolysis troubles. The higher the potential gradients in different parts of the system the more frequently the insulating joints must be used. In most cases it would not be necessary to make every joint insulating, one-third or one-fourth of the joints being usually sufficient even under severe voltage conditions, while in many parts of the system a much smaller percentage would suffice. Where new lines are being laid it is a comparatively simple matter to insert the necessary number of such joints, but in the case of old systems the expense becomes great, unless the potential gradients in the earth are first reduced by other means, so that a comparatively small number of insulating joints will be sufficient. Chiefly, for this reason, we do not in general recommend this method as the principal means of protecting pipe systems already laid with the lead joints. When, however, proper precautions are taken such as those described in detail in a later part of this report to reduce potential gradients to a comparatively low value, such, for example, as 1 volt per 1000 feet or less, this method of insulating joints may well be applied for the purpose of eliminating such residual electrolysis as might otherwise still occur if the system were not so protected. With potential gradients reduced to approximately the limit mentioned, a comparatively small number of insulating joints not exceeding 5 or 10 per cent of the total number would be sufficient to give practically complete protection to the pipes. We wish to emphasize, however, that we regard this method as valuable chiefly as an auxiliary method which may be used in connection with, and supplementary to, a negative return system of proper design.

3. PIPE DRAINAGE SYSTEMS

A system of electrolysis mitigation which has received wider application in this country than any other method is that which is best characterized as the "Pipe drainage system." This method has taken a variety of forms, the principal ones being as follows:

(a) **Direct Taps Between Pipes and Rails.**—In this form no extensive negative feeder system is used, but at various points throughout the positive areas where the pipes are close to the tracks, short heavy cables are connected between the pipes and rails with the view of keeping the pipes at nearly the same potential as the tracks. It is true that by the use of a sufficient number of such taps it would be possible to prevent any considerable difference of potential between pipes and tracks, but this does not insure relief from electrolysis. In order that such equality of potential may exist it is necessary that the potential gradients along the pipes throughout the region affected shall be the same as in the rails and under the conditions which commonly prevail in the positive areas this potential gradient is quite high, usually reaching several volts per 1000 feet and often 5 to 10 volts per 1000 feet, and even higher. Such gradients are sufficient to produce heavy current flow in the pipes and in case occasional high-resistance joints are encountered the heavy fall of potential across the joint will generally cause large leakage of current around the joint and rapid injury to the pipes. In case of local defects developing in the track bonding, practically all of the railway current may be forced to return via the pipes and the danger of excessive leakage is largely increased.

(b) **Negative Feeders to Pipes.**—Another form of pipe drainage consists in running negative feeders direct from the negative bus to various points of the pipe system. This form of pipe drainage has three practical embodiments. In one of these uninsulated negative feeders are run from the bus bar and tied to the pipes, some directly at the power house and others at more remote points. In this case the longer feeders have to have a very large cross section or else the resistance will be so large that they will draw very little current from the pipes and their purpose will be

thus defeated. In some cases it has been proposed to run these long feeders parallel to the pipes and tap them to the pipes at frequent intervals. It will be quite evident that this arrangement is open to the same objection as the plan of using uninsulated negative feeders to rails, in that it leads to large expense for copper, particularly in case it becomes necessary to carry the feeders to points far from the power house. In order to overcome this difficulty in some installations boosters have been connected to the longer feeders, in which case they can be made much smaller and by proper excitation of the booster any desired amount of current can be taken from the pipes by each feeder. There seems to be no reason why the same results can not be obtained by omitting the boosters and inserting resistance in the power house tap and in the short feeders, since in this way any desired distribution of current in the feeders can be obtained without the complication and operating cost of the boosters. The advantages of this latter plan would be very great in the case of a large system, since with the booster system a separate booster would be required for each feeder. The use of resistance taps can, as a rule, be made both economical and effective when used in connection with a somewhat similar system applied to rails, as described later.

We can not here go into detail in regard to the advantages and disadvantages of the pipe drainage system but will mention a few of the more important considerations respecting it.

First, it has been objected that it is not a permanent system, requiring constant watching and changing when the distribution of the street railway load or of the pipe systems undergoes any marked change. This objection is no doubt an important one where the insulated system of pipe feeders is used, but it would not be of serious moment in the case of the insulated feeders with resistance taps, since by the insertion of proper resistances in the various feeders they could be adapted to widely varying conditions as regards load distribution.

A second objection, already referred to, is the fact that any form of pipe drainage will necessarily increase to a greater or less degree the amount of current carried by the pipes, which is accompanied by the ever-present danger of trouble developing on high-

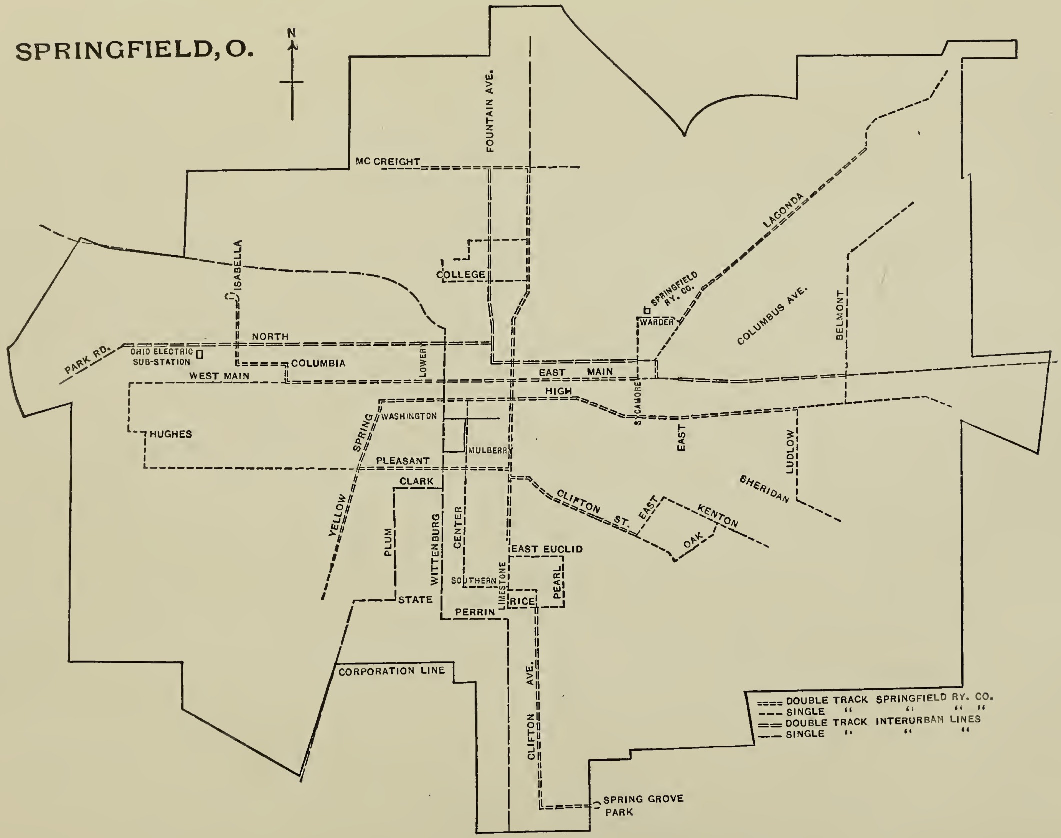

Chart No. I.—*Railway systems of Springfield, Ohio*

resistance joints at obscure and unlooked-for places. This objection is much more serious in the case of direct taps between pipes and rails and uninsulated pipe feeders than when boosters or resistance taps are used, since in the latter cases a proper distribution of current can be maintained that will greatly reduce this danger, although it can not eliminate it to a satisfactory degree.

A third objection is that the connection of the pipe system to the bus bars or rails lowers the potential of the pipes and tends to make them negative to other pipe and lead cable systems, thereby endangering the latter. The advocates of this system attempt to avoid this objection by recommending that all pipe and cable systems be included in the installation. This is sometimes practicable and sometimes not, depending on local conditions; but in any case it would greatly extend the area in which acute troubles might be expected and the expense of watching and guarding against trouble would be largely increased.

A fourth objection, resulting from the great tendency of this system to increase the current flow in the pipes, is the increased life and fire hazard which it introduces, particularly in connection with gas systems. The failure to properly bond the pipes before making any disconnections, or the accidental opening of the bond while the pipe line is broken, is likely to ignite escaping gas with more or less disastrous results to both life and property

A fifth objection, and an important one, is that the application of this system requires that all pipe systems to which it is applied shall be electrically continuous throughout. In addition to the possibility of high-resistance lead joints already pointed out we are confronted with the fact that in a great many installations, cement joints, rubber gasket joints, and other insulating joints are now largely used. Where used, these will usually be found distributed to a greater or less extent throughout the system, and if the drainage plan were applied to a pipe system containing any considerable number of these insulating joints it would result in the certain destruction of many of them within a comparatively short time. As a rule the points at which isolated insulating joints occur, or those in which the insulating jointed sections connect to the lines having lead joints, would be the

ones that would be in greatest danger. For these reasons the application of a general plan of pipe drainage as the chief means of electrolysis mitigation would be particularly unfortunate in case any one of the pipe systems contained any considerable number of insulating joints.

A sixth objection to the general application of the pipe drainage system as a means of electrolysis mitigation arises from the tendency toward the production of an excessive amount of alkali at the surface of a negative electrode imbedded in earth. This will occur to a much greater extent in some soils than in others, depending on the chemical content of the soils. The concentration of alkali at the negative terminal will have no detrimental effect in the case of iron pipe, but may tend considerably to increase the self-corrosion in the case of lead service pipe. If the soil is of such a nature as to present favorable conditions for the production of alkali at the negative terminal, considerable increase in the corrosion of lead services may be expected from this source provided the pipes are maintained too strongly negative throughout a large part of the day. Further, the application of the pipe drainage system makes the pipes more strongly negative throughout the entire system, and it is undesirable to create this condition unless it is known that local soil conditions are such as not to give rise to any serious increase in alkalinity under the voltage conditions that would exist.

What appears to us, however, as being the greatest objection to the pipe-drainage system, and this applies also to all the other methods mentioned above, is the fact that they are designed to relieve the symptoms rather than to remove the cause of the trouble. They are, therefore, fundamentally in the nature of palliatives, rather than remedies. In general, our study of the pipe-drainage method has convinced us that while it may under certain conditions be useful as a secondary means of lessening trouble, its installation as the principal means of electrolysis mitigation is an unwise procedure, not so much because the immediate consequences are bad, because the contrary is quite the rule, but because of the ultimate consequences to which this method, when once resorted to, must inevitably lead. In its practical working out it exhibits two opposing tendencies, viz, (1) the reduction of

the difference of potential between pipes and rails in the positive areas, with consequent reduction of damage at those points, and (2) an increase of the danger to the pipes throughout the entire system, as indicated above. As a rule, in the early stages of its application the effect is apt to be apparently beneficial, reducing the danger in positive areas more than it increases it elsewhere. As the system grows, the load increases; more and heavier bonds or cables become necessary, and the current in the pipes may become so great that the consequent damage due to the causes above mentioned will be of greater moment than the reduction of troubles in the positive areas, and any further extension of the drainage becomes a menace to the system. It is due largely to this slow and obscure manner in which trouble develops that has caused this method to be so widely used. Since it transfers the trouble from where it has been most evident to a new locality, where perhaps it may require several years to manifest itself anew, there is sure to be a lull in the storm which creates a favorable impression very difficult to dispel even when trouble later recurs. In some more recent installations it has been proposed to limit these secondary effects by placing a limit on the amount of current taken from the pipes by the drainage cables, the plan being that when this total drainage current reaches, say, 10 per cent or thereabouts of the total railway load, the track conductivity is to be increased by copper cables in order to keep the drainage current below the prescribed limit. In some systems which we have investigated in which the unlimited pipe-drainage system has been applied, it has been found that in order to reduce the potential condition to the desired limits it was necessary to draw from the pipes from 40 to 50 per cent or more of the total railway load. It is evident that if we attempt by means of ordinary uninsulated negative copper cables to decrease the total leakage to 10 per cent, the cost of the copper required will be so great as to render the plan wholly impracticable. We confidently believe that a system worked out on these lines will ultimately lead to much greater expense and less satisfactory protection than will result from other installations designed along the lines outlined in a later section of this report.

Among other methods that it has been proposed to apply to pipe systems for protecting them from electrolysis may be mentioned (a) chemical protection, which contemplates surrounding the pipes with certain chemicals, such as lime, etc., which are known to have a tendency to inhibit corrosion under certain circumstances, (b) the use of cement coatings on the pipes, (c) cathodic protection, or protection of pipes by maintaining them negative to certain structures by means of battery, motor generator, etc., (d) favorable location of pipes with respect to rails, (e) the use of noncorrodable conducting coatings, and (f) what may be termed electric screens which are sheets of metal placed near to or surrounding a portion of the pipe and electrically connected thereto. It is not necessary to discuss these at length here, as such a discussion will be found in publications of the Bureau of Standards to be issued shortly, and it need only be said that our investigations have convinced us that none of these methods can be considered seriously in connection with the permanent mitigation of electrolysis.

B. METHODS TO BE APPLIED TO THE RAILWAY SYSTEM

None of the systems of electrolysis protection mentioned above have to do with the nature or condition of the street railway return system, and in the practical working out of such methods the railway return system is usually ignored. The currents are permitted to stray from the tracks without restriction, and the sole purpose of the methods outlined is either to prevent their entrance into the pipes, or, if they are permitted to enter, the aim is to provide means for their exit with as little injury to the pipes as possible. It would appear more logical to attack the problem by beginning at the source of the evil and to prevent, to a large extent at least, the leakage of the currents from the railway return conductors into the earth. This is the more emphasized by the fact that in the past where such mitigating measures have been applied to the pipes the burden of providing the protection has usually fallen where it does not properly belong, namely, on the injured party and not on the party causing the injury.

We shall now consider what measures may be applied by the street railway companies to their own systems with a view of removing or at least greatly relieving the cause of the trouble.

Of the various methods that have been proposed for application to the negative return of the railway system, the majority are either inadequate or unsuited to the situation in Springfield. Among these may be mentioned alternating-current traction, three-wire systems, the use of negative trolley, grounding of tracks and bus bars, periodic reversal of trolley polarity, and the use of the double-trolley system. There is no question, of course, but that the double-trolley system, if properly installed, would eliminate entirely electrolysis from railway currents. This system as at present used in Cincinnati, Ohio, and Havana, Cuba, and the corresponding underground conduit systems as used in Washington and parts of New York City eliminate almost completely the danger of electrolysis, the small leakage which does occur being of no practical consequence. The chief objections to its use are the cost of installation and the increased operating difficulties which it involves. The cost of installation in fact does not appear to be justified merely as a means of electrolysis protection, inasmuch as a very satisfactory degree of protection can be obtained by other and much more economical means.

4. CONSTRUCTION AND MAINTENANCE OF WAY.

Proper maintenance of the track in order to secure high conductivity is everywhere recognized as a necessary condition in electric railway operation, but it does not always receive the attention that its importance justifies. In the matter of joints alone there is a very wide diversity of practice. In recent years, however, engineers have rapidly come to recognize the futility of trying to maintain a proper state of track conductivity by merely bridging the joints with short copper bonds. Such construction is still used, but it is finding much less favor than formerly, and in most of the larger and better maintained systems these methods of shunting the joints are used, if at all, chiefly as secondary expedients. The tendency now is to make the joint itself electrically continuous rather than to shunt around it, although both methods are not uncommonly combined.

The methods whereby more or less perfect continuity of the joints is obtained embrace the various types of welded joints such as electric welds, thermit welds, etc., and those joints in which a

second metal such as zinc and its alloys are employed to form the junction. Of these latter the well-known Nichol joint made by pouring molten zinc between the fishplates and the rail ends is one of the most effective, and has given very satisfactory service for a number of years. The zinc is poured in after the fishplates are bolted on and the expansion of the zinc which takes place on solidifying makes a firm and permanent contact between the fishplates and rail ends. Joints made either in this way or by any of the various welding processes have, as a rule, a lower resistance when new than an equal length of rail, and for the most part have given good satisfaction in service, although some trouble has been experienced, particularly in welded joints, due to parting of the rails at the weld. Experience to date, however, indicates that these joints are very satisfactory in all cases where the tracks are laid in paved streets, or otherwise suitably reenforced. As a precautionary measure, however, some engineers prefer to bond over all joints also. In the case of welded joints we believe this to be good practice, but experience seems to make it appear unnecessary in the case of the Nichol joint.

Cross bonding between the rails is also much resorted to as a precaution against the troubles arising from bad joints. If such cross bonds are properly installed and maintained at sufficiently frequent intervals, the deleterious effect of occasional bad joints is almost entirely eliminated. These cross bonds are usually placed at intervals of from 200 feet to 500 feet and those distances are sufficient if the cross bonds and rail joints are fairly well maintained.

All special work should be shunted by copper cables capable of carrying all of the current passing over the tracks at that point. In many places this is the regular practice, but it is often neglected entirely or poorly maintained, and in some cases the drop across special work has given rise to very serious electrolysis. The remedy is so simple and effective that only carelessness can account for the existence of trouble of this nature.

A properly drained roadbed is also a very effective aid in reducing the leakage of stray currents from the rails. The amount that can be accomplished in this way will of course vary greatly with varying conditions so that no specific recommendations can

be made here, other than to point out that since the conductance of the leakage path is largely dependent on the amount of moisture which is contained in the material forming the roadbed and the earth beneath, any construction which tends to reduce the average moisture content therein will reduce in corresponding degree the magnitude of the leakage currents. Indeed, we have made tests on long lines of track without intersections to cause complications, in which it was found that leakage from the rails had been almost entirely eliminated, the reason being that the road was so constructed that the leakage path from rails to earth was on the whole of high resistance. We believe that much more could be accomplished by this means than is commonly supposed, without materially increasing the cost of construction, although it must not be regarded as a satisfactory primary means of electrolysis mitigation.

5. UNINSULATED NEGATIVE FEEDER SYSTEM

This system has been much used in this country as a means of increasing the conductance of the track, especially in the regions near the power houses where, as a rule, the current densities become high. The benefits that accrue from its use are threefold, viz, the reduction in potential drops on the rails, thereby lessening damage due to electrolysis; the saving in power; and the maintenance of a more uniform voltage on the cars, especially at times of peak load, thus giving rise to improved car service and car lighting and reducing the maximum demand. When these benefits are carefully considered it seems somewhat surprising that the use of negative feeders is not more common than it is. While we do not regard this as being in general an economical system, it is proper to consider here its merits as compared with systems in which no feeders are used. In the matter of the second item—the saving in power—it is easy to show that in this feature alone much can be gained by the addition of negative copper. With feeders costing $4000 per mile installed for cables of 1 000 000 circular mil section, the most economical potential gradient to allow in the rails is about 3 volts effective per 1000 feet (root mean square for 18-hour period) with power costing 1 cent per kw-hr Wherever the potential gradient exceeds that figure the addition

of copper in parallel with the rails produces an annual saving more than sufficient to pay all proper charges, including interest, taxes, and depreciation on the copper required to reduce the potential gradient to 3 volts. With energy costing 2 cents per kw-hr the most economical gradient limit is a little over 2 volts per 1000 feet. When these values are exceeded in any locality, that section of the track is not only being operated at an unnecessary loss, but conditions as regards electrolysis are unnecessarily bad, much worse in fact than they would be under the more economical installation. If we attempt to carry the voltage limit below this value, the cost of the necessary copper increases very rapidly and soon becomes prohibitive. On the other hand, it is generally recognized that a potential gradient of 3 volts per 1000 feet is much too high to permit a reasonable degree of immunity from electrolysis, so that some other method must be employed if a fair degree of economy is to be maintained. Such economy is afforded in varying degree by the insulated negative feeder systems which we shall now consider.

6. INSULATED NEGATIVE FEEDER SYSTEM

In this system, instead of tying the tracks directly to the negative bus and depending on the tracks, and such copper as may be in parallel therewith to return the current to the power house, the connection at the power house is either removed or given a suitable high resistance and insulated feeders are run from the negative bus to various points of the track, as shown in Fig. 4. By this means two important results may be achieved. In the first place, the current being taken off of the rails at numerous points, high-current densities, and consequently high potential gradients in the rail are avoided. In the second place, it is possible, by so designing the system that the drop of potential on all of the feeders is the same, to so subdivide the current flow in the tracks that the direction of the flow will be frequently reversed, thus preventing the accumulation of large potential differences between points on the tracks some distance apart. It will be evident that in this case the actual drop of potential on the different feeders is of secondary importance so long as it is practically the same in all, in so far as the potential differences in the track are concerned. We can thus impose any desired potential restrictions on the track and still be free to

design the feeders to give maximum economy, something we can not do when the feeders are connected in parallel with the tracks as is most commonly the case.

RAIL DROP

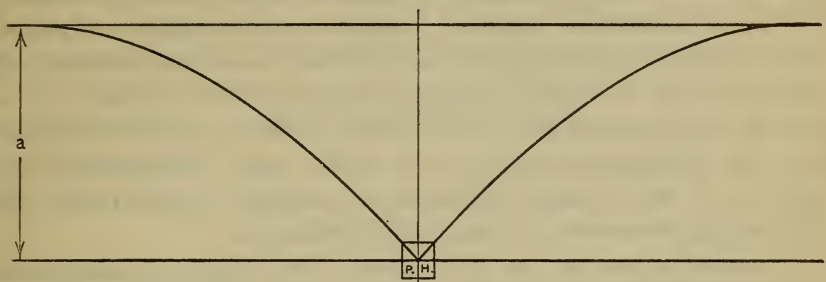

Fig. 3

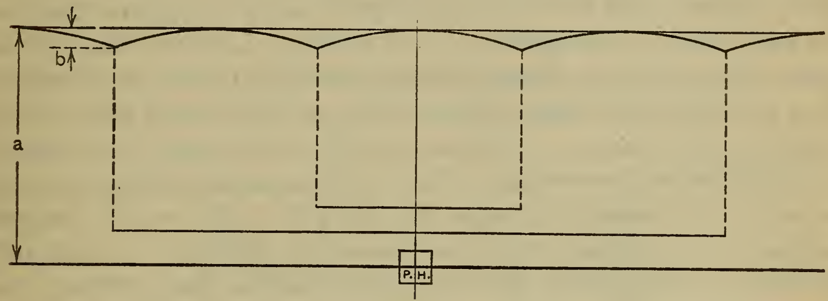

Fig. 4

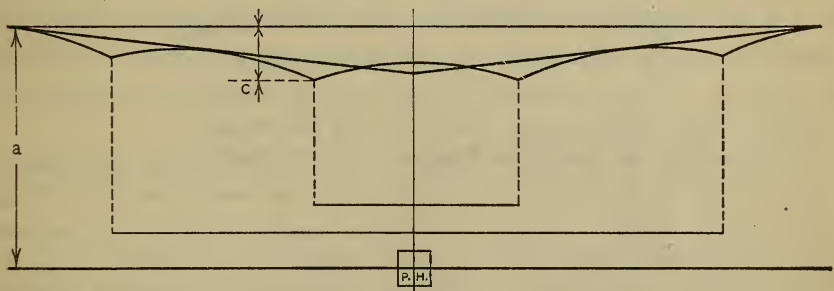

Fig. 5

Figs. 3, 4, 5.—*Effect of insulated feeders in reducing rail gradients*

A graphic representation of what can be accomplished by using a system of insulated feeders of this sort is shown by Figs. 3, 4,

and 5.[2] Fig. 3 shows the arrangement of a negative return in which no negative feeders are used and the rails are tied directly to the negative bus at the power house, a uniform distribution of load being assumed. The curve at the top shows how the potential of the rails vary from point to point. Fig. 4 shows the same system with insulated negative feeders run to a number of points on the track, and so organized as described later that the drop of potential is the same on all during average condition of load. It is seen that the current flow in the tracks is here so subdivided that the total differences become very small, and consequently the tendency to set up large differences of potential between rails and surrounding structures is practically eliminated.

An examination of the two curves shows that the maximum potential difference in the rails has been reduced to one-sixteenth of its former value by the installation of only two negative feeders on each side of the station. It is evident, however, that these great reductions in potential differences in the tracks are obtained at a sacrifice of the track conductivity, of which very little use is made in the latter case. Between these two extremes any desired compromise can be obtained; that is, if instead of making the drop on all of the feeders the same we make the drop on the feeders smaller as we approach the power house, we shall have a continual gradient in the rails all the way to the station, thus utilizing the conductivity of the tracks to any desired extent. This will result in a more economical installation but at the expense of somewhat greater potential differences in the track return system, as shown in figure 5. These insulated-feeder systems embrace a number of modifications, chief among which are the following:

(a) **Boosters in Separate Feeders.**—A method that has found considerable application in Europe but is comparatively little used in this country is that of carrying insulated negative feeders to various points on the track and inserting a booster in each feeder or group of feeders. The advantage of this method is that by varying the voltage of the individual boosters, almost any desired potential conditions can be obtained in the track network.

[2] The figures are reproduced from a more comprehensive report previously issued, and figs. 1 and 2 of that report are irrelevant to the present test and are therefore omitted.

To offset this advantage we have, among other things, the large first cost of the boosters and an increased depreciation and operation cost. In a large district as many as a dozen or more negative feeders may be required, and the use of a booster with each of these would obviously introduce considerable complication in the operation of the station. Figure 6 shows in diagrammatic form an insulated negative feeder system with multiple booster control.

MULTIPLE BOOSTER SYSTEM

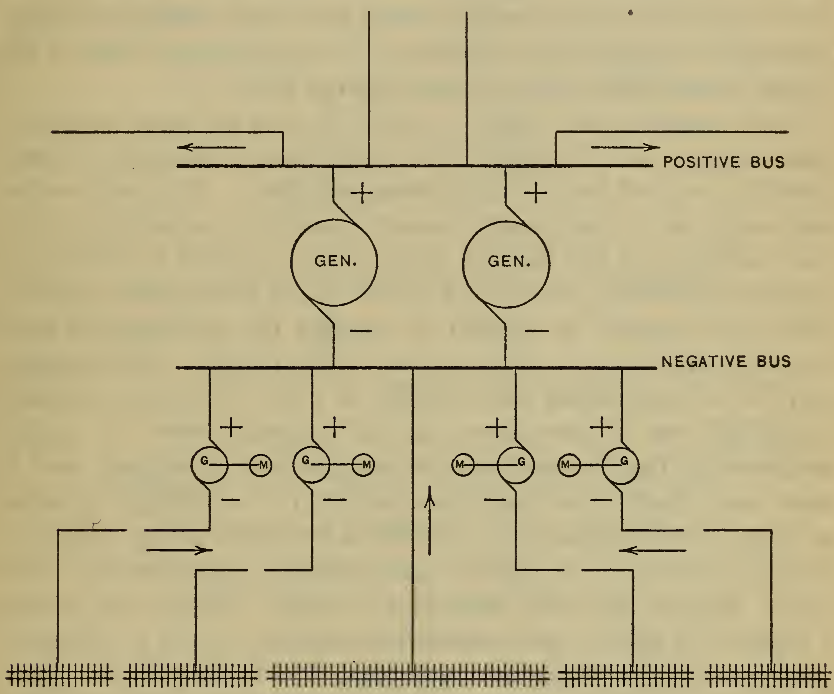

Fig. 6

In this, as in all other insulated negative feeder systems, the most important characteristic is the fact that the potential gradients may be kept low without regard to the total drop on the negative return between cars and bus bar. If the voltage of each booster is kept about equal to the total drop on the cable to which it is connected, the potentials of the various points of tap to the rails will be approximately the same, so that large differences in

potential between different points in the track will not occur. In consequence of this the copper feeders can be designed solely from the point of view of economy and thus a much more economical installation can be obtained than would be possible with an insulated feeder system, in which the drop on the cable must be no greater than the drop on the rails. When it is desired to reduce the potential gradients in the tracks to 1 volt per 1000 feet or lower this method is much more economical, all costs considered, than the uninsulated negative feeder system mentioned above, the saving of first cost of copper being more than sufficient to compensate for the cost of the boosters and the capitalized value of the annual depreciation and increased energy loss.

These boosters are usually driven by one or more constant-speed motors, and the fields of the boosters are separately excited, a certain range of hand control being provided. The ideal excitation would be to have each booster excited in proportion to the load delivered to the district drained by the cable to which the booster is connected, but this, as a rule, is not practicable, and best results will usually be secured by making the excitation of each booster proportional to the total load on the system. One arrangement for accomplishing this is shown in Fig. 7, in which a booster equalizing bus is introduced on the negative side. A similar arrangement can be used on the positive side if desired, and in some cases where local conditions warrant it, the different boosters may be excited separately by individual feeders or groups of feeders supplying power to the region corresponding approximately to the region drained by each particular booster. While this system is capable of giving very satisfactory results, so far as potential conditions in the tracks are concerned it is to be seriously questioned whether the expense and complication of it is justified, particularly in view of the fact that practically as good results can be obtained by other methods which are simpler to install and operate and at the same time much cheaper in point of both first cost and maintenance. The sole advantage of this system over those described below is that a somewhat more flexible control over the individual feeders is obtained, but this is of doubtful value, since the simpler methods afford practically all that is needed in this respect, as will presently appear.

(b) **Insulated Negative Feeders Without Boosters.**—In this system the layout of the negative feeder system will be very similar to that in the case of the booster system described above, the chief difference being in the elimination of the boosters. The potential necessary to force the required current through

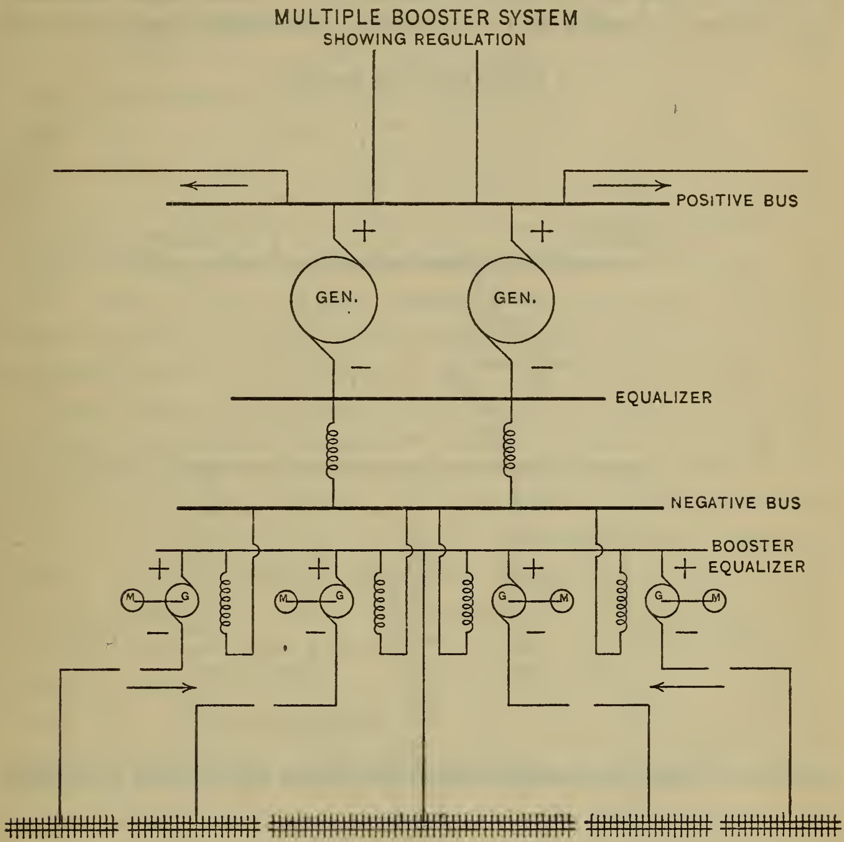

Fig. 7

the negative feeders without the use of additional copper is obtained by removing the direct tie between negative bus and rails at the power house and substituting in its place a properly designed resistance tap. The layout then becomes substantially as shown diagrammatically in Fig. 8.

In designing the feeders a careful study is made of the load distribution over the entire territory supplied by the station under consideration, and from this study the most natural points for taking off the current are selected and the number of amperes to be taken off at each point determined. A preliminary value of potential drop on the first feeder is then assumed and from this drop and the current to be carried by the feeder together with

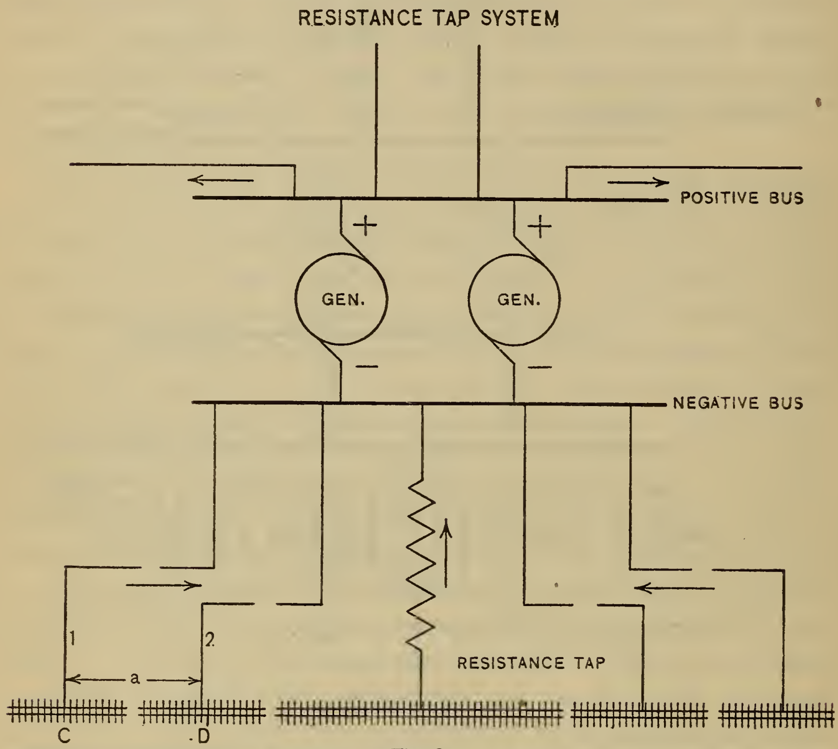

Fig. 8

its length the cross section of the feeder must be designed consistently with this, so as to avoid potential gradients in the tracks greater than the value determined upon as the limiting allowable average gradient. Beginning thus with feeder No. 2 its drop is the drop on No. 1 minus the allowable drop on the distance (a) between the points at which the two feeders tap the rails. For instance, if the assumed drop on No. 1 is 15 volts

and the distance between the two taps is, say, 1200 feet and we are permitting a maximum drop of 1 volt per 1000 feet in the tracks, the average gradient between C and D will, in general, be less than this figure, depending on the amount of load originating between these points. The average value of this can be determined from the car schedule. Assuming it to be 0.7 volt, for example, the total drop between C and D will be 0.84 volt. The total drop on feeder No. 2 will therefore be $15-0.84=14.16$ volts. From this value and the current assigned to this feeder its cross section can be calculated, the length being, of course, already fixed. We proceed in a precisely similar manner for the other feeders and the resistance taps near the power house. Sometimes the cross section of the feeders as thus calculated will be too small to carry the required current without overheating, and when this is the case the feeder must be made sufficiently large to carry the current and an additional resistance inserted, preferably at the power house, to give the necessary voltage drop.

When this calculation is completed we are ready to determine whether the original assumption made in regard to voltage drop on the first feeder was the one that would give approximately the most economical installation. To determine this we sum up the total cost of the feeders installed, and determine the proper annual charge, including interest, taxes, and depreciation, and also calculate the total annual value of the energy lost in the feeders and resistance tap. If these are approximately equal, the voltage drop assumed was the proper one. If, however, the annual charge on the feeder system is less than the cost of lost energy, the voltage assumed is too high and vice versa, and a correction must be made. This correction can be very easily and simply applied without recalculating the feeder system, as in the first instance. For example, if the annual cost of the feeders is found to exceed that of the energy lost by 20 per cent, we must increase the mean voltage drop by 10 per cent and reduce the area of the feeders by about 10 per cent which change will bring the costs to approximate equality, the condition for most economical installation. If E_1 is the original voltage drop calculated for any given feeder and E_2 is the mean voltage drop for all feeders, weighted according to the current in the feeders, then the increase of voltage on

any feeder being $1/10\ E_2$ we must reduce the cross section of the feeder by the factor $\dfrac{E_1}{E_1 + \dfrac{E_2}{10}}$. The value of E_1 in each case is the initial voltage drop calculated for that particular feeder, so that each feeder is corrected by a different factor. When the correction is made in this way there is no appreciable change in the potential gradient assumed for the rails.

At first thought it might be considered that the introduction of feeders of this sort, together with a resistance tap at the power house, over which a considerable potential drop is allowed, would cause an objectionable increase in the power lost, with consequent reduction in voltage on the cars. This would be true in some cases where the voltage drop on the rails is already low, but on the other hand there are many practical cases where the present drop on the rails is large, in which the reverse is the case. With power costing 1 cent per kw-hr the most economical drop of potential on the copper cables is nearly the same as the value given in the case of uninsulated feeders, viz, 3 volts per 1000 feet. If the power lost in the resistance tap is a large part of the total, the most economical gradient will be somewhat smaller. Detailed calculations show that if the initial potential gradients in those portions of the track to be paralleled by the feeders is much above 3 volts (root mean square for 18 hours), an actual saving of power will result from the installation of the negative feeders, the saving in the rail loss being more than sufficient to compensate for the loss in the feeders and resistance tap. For the same reason the average potential at the cars will be increased. It has been pointed out above that the rail gradients in many instances greatly exceed this value, and in such places there would be a substantial saving in power resulting from the installation of this system. In other places there will be some increase in the loss, and as a rule it is believed that the total negative losses will not be greatly affected by the installation of a feeder system of this character. Only a detailed calculation for each individual case can determine whether the net effect as regards power loss will be a loss or a gain.

The simplicity of this system as compared with the negative booster system is obvious. In fact the chief objections that have

been urged against the negative booster system are overcome, viz, the cost of booster equipment, together with elaborate switchboard apparatus for controlling the same, the space occupied by the boosters, which is out of all proportion to their kilowatt capacity (because of the large number of small machines required) and, finally, the time and expense involved in caring for these machines. In the matter of power loss there is probably little to choose between the two methods. In either case the loss in the cables would be approximately the same, since all but the very short cables would be designed for maximum economy. The difference in power loss would be approximately the difference between the losses in the boosters and the loss in the resistance tap. The efficiency of such small motor-driven boosters, operating at a low load factor would hardly exceed 60 per cent, so that if the loss in the resistance tap is less than 40 per cent of the total feeder loss, the latter plan would give rise to even less power loss than the booster method.

Against these decided advantages of the resistance tap method over the booster method must be set the objection that the former is less flexible than the latter, and can not be made to respond as readily to meet the exigency of shifting loads. The importance of this objection is greatly minimized by two considerations, the first of which is that the really important consideration is to take care of average normal conditions, and this the system will do automatically if properly designed. Abnormal conditions, such as blockades or other temporary bunching of the load in one locality are usually of so short duration that such disturbances in the rail gradients as would result therefrom would have no appreciable influence on the electrolysis problem. The second consideration is the fact that a large measure of flexibility can be imparted to the system by providing means for varying to a slight extent the resistance of the individual feeders at the power house. Since the voltage drop on any feeder will, as a rule, be of the order of ten or more times the voltage drop on the rails between adjacent feeder taps, a change of 10 per cent or less in the resistance of a feeder or group of feeders would take care of a shifting of the load tending to produce local variations of 100 per cent in the rail currents. Such resistance control can be

accomplished in a comparatively simple and economical manner, and throughout sufficient range to meet most practical requirements, although it will not be possible in this way to secure the same degree of flexibility in the feeder control as by the use of separate boosters in each feeder. However, this method is a thoroughly practical one, and if properly installed can be made to reduce potential gradients in the rails to any desired degree, and under many circumstances it is the most economical effective means that can be installed for preventing electrolysis. Under certain conditions, however, as in the case of a power house or substation located in the center of a dense network of rails in which a large amount of current can be brought close to the bus bar on the rails or very short feeders, the power lost in the resistance tap might become so large as to be an important matter, and to make this system less economical as well as less flexible than the systems described below.

(c) **Single Booster System.**—This system is designed to eliminate to a large extent the disadvantages of two systems just described, namely, the insulated negative feeder systems with and without boosters. As pointed out above, the chief objections to the use of the direct boosters in the negative feeders arise from the large number of machines that will be required in most cases, the consequent increased depreciation, operating difficulties and space requirements, and to the fact that the small size of the individual machines render a high efficiency of operation out of the question. This will still be true as regards the generator part of the boosters even though all of them are driven by a single motor, as can often be done. In the case of the insulated system without boosters the elimination of these difficulties is accomplished through the sacrifice of a considerable measure of the flexibility of the booster system, and at the expense of the added power lost in the resistance taps, which latter may become serious under the conditions pointed out above. The single booster system occupies a somewhat intermediate position between these two extremes, preserving to a large degree the flexibility of the one and simplicity of the other, while yielding under some conditions an economy of operation greater than either. The system is represented diagrammatically in Fig. 9. It will be seen that all of the negative

feeders except the power house tap are brought to a feeder bus and that a single large booster is connected between this bus and the negative bus of the generators. In this case the proper distribution of current between the different outlying feeders is secured by a proper proportioning of their resistances, as in the case when boosters are not used. Here, however, the power house tap, instead of being connected to the negative bus through a resistance,

SINGLE BOOSTER SYSTEM

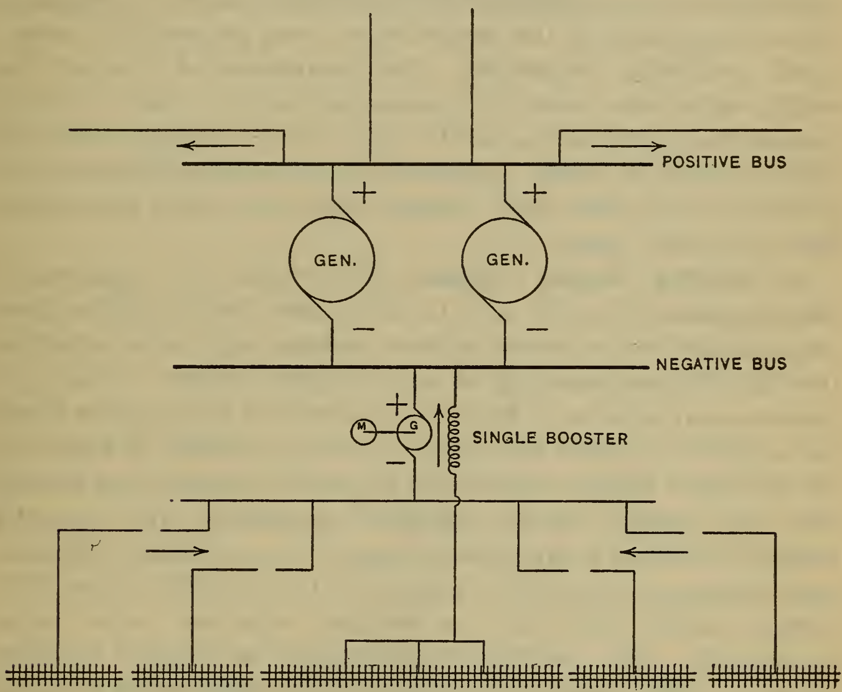

Fig. 9

is led through the field of the booster. In consequence of this the voltage tending to force current through the feeders is proportional to the current in the power house tap, and hence the proper division of current between the two sections is automatic. It will of course be obvious that very short feeders such as those running to various street intersections adjoining the power house would be combined with proper ratios of resistance and led to the

field of the booster as a single feeder, as indicated in Fig. 6. The advantages of this over the method without boosters is that the power loss in the resistance tap is eliminated and the distribution of current between the outlying feeders and those near the power house can be controlled throughout any desired range by properly shunting the booster field. Further, and this is of special importance, the distribution being thus adjusted to any desired ratio, it will automatically be maintained at approximately that ratio regardless of the magnitude of the load, and in this way overloading the rails approaching the power house, even temporarily, is rendered practically impossible. The importance of this will be readily appreciated when it is considered that it is this local overloading that is responsible for the rapid fall of potential in the rails which in turn is chiefly responsible for the large differences of potential which often occur between pipes and rails in the regions near the power house.

(d) **Inverted Booster System.**—This system is represented diagrammatically in Fig. 10. It will be seen that this differs from the insulated feeder system without boosters only in the substitution for the resistance tap of an "inverted booster"; that is, a booster so arranged as to produce a counter emf in the power-house tap sufficient to cause the proper amount of current to flow over the insulated feeders and prevent excessive currents from flowing over the tracks. In its practical embodiment this inverted booster consists of a series motor coupled to a practically constant-speed generator connected to either the D. C. bus bars, or the A. C. system, in the latter case an ordinary induction motor being satisfactory. The counter emf of the series motor gives the drop required on the feeders, and the power consumed by the motor in excess of the losses is returned to the system through the generator end of the unit. By a proper design of the field characteristic of the series motor the counter emf of the machine may easily be made practically proportional to the current taken from the tracks by the motor, and it will be obvious, therefore, that the drop on the feeders and consequently the current taken by them will be nearly proportional to the motor current, which is approximately the condition desired. The operation is therefore entirely automatic

for normal load conditions, and such special control as may be necessary because of changes in track conditions near the power house, or to other causes, can readily be secured by an adjustable shunt on the series field or by providing a certain amount of separate excitation in addition to the series field.

It will be evident that as long as the railway load is sufficiently large, so that the input into the series motor exceeds the losses in

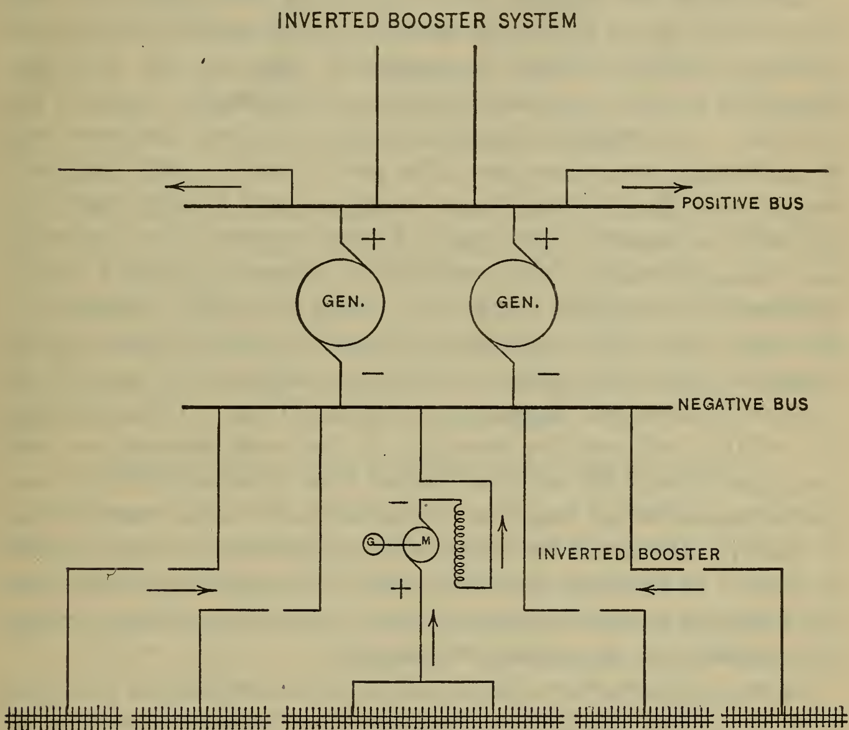

Fig. 10

the unit, the generator will return the excess to the system, but if the input into the motor is less than the losses, both machines act as motor, the generator end carrying the excess of the losses. If the generator consists of an ordinary shunt-wound D. C. machine, or a properly designed induction machine, only a slight drop in speed accompanies this change from generator to motor action, so that the counter emf of the series motor remains practically pro-

portional to the current input. By a proper design of the D. C. generator, such as by compound windings, working well up on the saturation curve, it would be practicable to make the counter emf of the series motor rise either faster or more slowly than the current input wherever such special conditions might be made desirable by local conditions, but this will not, as a rule, be necessary.

Considering the relative merits of the last three methods, it will be seen that in so far as the distribution of current between the different outlying feeders is concerned, they are all on a par, depending as they do on the resistance of the feeders for such distribution. As regards the distribution of current between outlying feeders and those near the power house, both the single booster and the inverted booster methods give greater range and flexibility of control of the ratio of these currents than the resistance tap, although a fairly satisfactory degree of control can be obtained by the latter method by using a variable resistance in this tap. As to first cost, the resistance tap will of course be the cheapest under all conditions while the relative first cost of the booster methods will depend on local conditions. If the distribution of the load and the character of the track network are such that more than half the total station load is taken from the track via the power-house taps, then a smaller and cheaper machine can be used in the case of the single booster than if an inverted booster be used. If, however, less than half of the current be taken from the tracks at or near the power house, the inverted booster will be the smaller and, in general, the cheaper.

In the matter of net cost, however, we are concerned not alone with the cost of installation but also with numerous other charges, such as the cost of energy lost, depreciation, and operating charges. If the character of the system be such that the greater part of the power of the station be taken from the taps at the power house, the single direct booster method would show to advantage over the inverted booster, and in most cases the saving in annual value of energy lost as compared with the loss in the resistance tap would more than pay all proper charges against the booster, as will be shown later. If, however, the current taken from the

tracks near the power house is less than half the station load, the inverted booster will be cheaper both in first cost and in operation than the direct booster and, except for quite small capacities, will show a saving in operating costs over the resistance tap. However, as the amount of current taken from the power house tap becomes smaller, a point is finally reached at which saving in power no longer compensates for the additional cost of the booster and the resistance tap becomes the cheaper. It will be seen, therefore, that the relative merit of the three systems depends on conditions which must be determined for each individual case, but in most cases either the inverted booster or the resistance tap will prove to be the most economical installation.

Combinations of two or more of these systems may often be found desirable, as, for instance, in the case of a number of comparative short feeders going to nearby points and one or two very long feeders extending much farther from the station. In such a case any one of the above feeder systems may be applied to the shorter feeders as a group, and a direct booster inserted in the long feeder to provide the voltage necessary to bring the average current flow in the cable up to the most economical value.

7. NUMBER AND LOCATION OF POWER HOUSES AND SUBSTATIONS

In a general way the effect of the number of feeding points on the potential drops in the rails and the consequent leakage of current from the tracks is obvious but some of the more important aspects of this problem are obscure and often not appreciated. The economic aspect of the question is also more complex than is generally recognized. In the broadest terms we may consider the matter under two heads, namely, (1) the effect of the number and location of the stations on the tendency of the pipe systems to pick up stray currents from the earth, and (2) the effect on the total drop of potential on both sides of the line. As to the first of these we have to consider the fact that as the number of stations is reduced the capacity of each must be increased, with the result that the current flow in the rails approaching the power house will be greater, and the increased potential gradients resulting therefrom cause correspondingly increased leakage of current from the tracks. Further, as the distance between stations is increased

the tendency of pipe lines to take up current from the earth under a given potential gradient increases much more rapidly than the distance of transmission. In fact it can be shown that the current picked up by the pipes may increase either as the second, the third, or even a higher power of the distance between feeding points, according to the character of the system under consideration. Any increase in the number of feeding points, or more properly speaking, the number of "drainage points" or points at which current is taken from the track, will reduce in much greater degree the flow of stray currents in the pipes. The number of drainage points can be increased to any extent desired by the proper use of insulated negative feeders as above outlined, but the fewer the stations the longer and heavier the feeders must be, and in consequence of this an increase in the number of stations may often prove to be in the interest of economy, considering only the negative return; this economy will become much more pronounced when we consider also the distribution of the power on the positive side as well as its return on the negative.

When we come to consider the question of total drop of potential in the distribution and return of the current, we have many complex factors to consider. One of these factors is the loss of power resulting from such drop of potential, but the calculation of the value of this lost power is by no means so simple as might at first appear. It is not sufficient simply to determine the total energy loss during any given time and multiply this by the cost of power per kw-hr in order to determine its value. We must consider that the loss of power is proportional to the square of the load and hence is greatest at time of peak load when the capacity of the power station is usually taxed to its utmost. The capacity of the generating plant and hence the fixed charges on the cost of power are thereby increased; or, if the power be purchased, there is usually a fixed charge imposed on the maximum demand. In any case if the operation of the system is such that the line losses give rise to an increased demand for power at time of peak load, the cost of the lost power will be greater than the cost of the power utilized at the cars.

Besides the question of lost power due to line drop we have to consider also the effect of this drop of potential on the character of

the car service and the cost of operation of the car system. Low voltage means lower average car speed, with a consequent increase in the number of cars required to operate at a given headway, which in turn increases both fixed charges and operating costs. Any change in the distribution system, therefore, whether a change in the number of stations or any other change which affects materially the line losses will exert a marked effect on the cost of operation of the system. In designing a system of electrolysis mitigation, therefore, many things have to be taken into account quite apart from the technical points regarding the electrical condition of the negative return if a proper balance is to be maintained between the cost of making the proposed changes and the benefits resulting therefrom.

In the foregoing brief review of the various methods that have been proposed for reducing troubles from electrolysis, a number were stated to be of little value for extensive application to networks of any considerable size, and certain of them were stated to be actually detrimental because of their tendency to accelerate deterioration of the pipes. The method of insulating joints and the pipe drainage system were stated to be of some practical value, but it was recommended that their use be restricted to auxiliary measures used in connection with certain of the track drainage systems. A more logical and at the same time a more effective and economical procedure is to attack the source of the trouble by applying remedial measures to the railway system. A number of methods are available for this purpose, but as pointed out in the foregoing review, the majority of these, viz, the "alternating current system," the "double trolley system," "three wire system," "negative trolley," "periodic reversal of trolley polarity," and "uninsulated negative feeders to rails," considered solely as methods of electrolysis mitigation were either impracticable or else open to the objection that the expense and operating difficulties attending their application were rendered unnecessary, because of the fact that there are other adequate methods available for general application which are comparatively cheap to install and which introduce but slight complication into the operation of the system. These latter methods are the four types of insulated negative feeder systems outlined above. It is

possible by the proper application of any of these methods to reduce the potential gradients in the earth to almost any desired degree, and they can consequently be made very effective in relieving electrolysis troubles. In special cases, however, it may sometimes be better, where conditions are favorable, to combine one of these methods with either the insertion of a moderate number of insulating joints in pipes, or with the use of a very limited amount of pipe drainage, the insulated feeder system being applied to reduce potential gradients throughout the system to a very low value, and one or the other of the auxiliary systems used to practically eliminate any residual electrolysis that might still remain. An additional advantage that would result from the proposed installation grows out of the more uniform voltage available at the cars. The rail drop being reduced to a small fraction of its former value the variation of car voltage will be chiefly that due to the drop on the positive side, and hence the voltage regulation at the cars will be materially improved. This gives rise to much more satisfactory car lighting, a matter of considerable importance to the traveling public.

In a later section of this report we present a summary of a plan of electrolysis mitigation that we deem best suited to existing conditions in Springfield. A study of these conditions has shown that the insulated feeder system without boosters offers the most economical effective solution of the problem. The plan has been worked out in detail, the size and location of each feeder being given, and the first cost of the installation and the economies resulting therefrom are carefully estimated. Conclusions drawn from these detailed calculations are that the economies resulting from this initial outlay make it, from the start, a dividend-paying investment, the saving being sufficient in itself to justify the investment quite apart from its effect in eliminating electrolysis troubles.

PART II. RECOMMENDATIONS FOR ELECTROLYSIS MITIGATION IN SPRINGFIELD, OHIO

As pointed out in the foregoing section, the most logical and effective method of securing protection against electrolysis troubles consists in eradicating the cause of the trouble by eliminating to a

large extent the escape of stray currents into the earth. It was shown that this can be very effectively accomplished by any one of a number of insulated negative feeder systems applied to tracks, and the relative value of the different types of these systems, both as to effectiveness and economy of installation and operation, was very briefly discussed. It has also been pointed out that the Springfield Railway Co. has already installed a feeder system of this kind, consisting of a number of insulated overhead copper feeders running directly from the bus bar to various points in the track return. The experimental data secured by the engineers of this Bureau show that this feeder system has brought about a material improvement in electrolysis conditions in Springfield; but, as already stated, some modifications of this system will be necessary before a satisfactory degree of protection will be assured. A study of the system as it now exists shows that with certain modifications, which are set forth in detail below, not only can trouble from electrolysis to the water and gas pipes be very satisfactorily eliminated, but that considerable economy in the operation of the system will likewise be secured. An examination of the present system also reveals the fact that certain other changes in the negative return circuit should be made in order to bring about the most satisfactory conditions from both the standpoint of electrolysis mitigation and economy and simplicity of operation. These various changes are discussed in detail below.

1. IMPROVEMENT IN RAIL JOINTS

The electrical measurements taken on the rails of the Springfield Railway Co.'s tracks and also the tracks of the Ohio Electric Co. show that it is desirable to give some attention to improving the continuity of the tracks, in order to secure the maximum benefit from the conductivity of the rails. It has already been stated, however, that the condition of the Springfield Railway Co.'s tracks on the whole is not considered particularly bad, but it is nevertheless important that the tracks be gone over and all bad joints carefully rebonded. The Ohio Electric Co.'s tracks at present are particularly bad, it being found that the Ohio Electric Co.'s current in large part returns over the tracks of the Springfield Railway Co.'s lines to the junction of Isabella and

North Streets, the double track on North Street east of Isabella carrying practically no current. We understand this is due to the reconstruction work which is now going on on the Ohio Electric Co.'s lines, and that within a short time this reconstruction work will be finished and the present bad condition of the track conductivity will be eliminated. This matter should be given careful attention, however, in order to insure that a good condition of the track is secured and maintained. Of the several other interurban lines running into Springfield, the power houses are so located and the load so light that they will not contribute appreciably to electrolysis troubles, provided their rails are properly bonded, the rails themselves being capable of affording all the conductivity that is needed for the light loads carried. With all the railway systems, however, it is very important that periodic tests be made on the tracks and immediate steps taken to improve the conductivity of any joints that are found to be of high resistance. In general the resistance of the joint should not be permitted to exceed that of two or three feet of continuous rail, it being entirely practicable to secure and maintain this condition with any one of a variety of rail joints without prohibitive expense.

2. INTERCONNECTION OF THE TRACKS OF THE OHIO ELECTRIC RAILWAY AND SPRINGFIELD RAILWAY COS.

A very important matter in connection with the elimination of the electrolysis troubles in Springfield is the proper interconnection of the tracks of the Springfield Railway Co. and the Ohio Electric Co. at all crossings. This is of prime importance not only because of the marked economy that would result from such interconnection, but also because of the fact that it would be practically impossible by any means to secure satisfactory electrolysis conditions if these railway tracks were not electrically interconnected. The importance of such a connection can readily be understood by reference to Chart I, which shows in diagramatic form the railway tracks of the two systems on North and Main Streets between the two power houses and also the cross tracks on Isabella, Wittenberg, Limestone, and Syracuse Streets and Lagonda Avenue. The tracks on North Street will have, when the present rehabilitation work is complete, rails weighing 90

pounds per yard, having a resistance of 0.00 24 ohms per 1000 feet, or about 0.024 ohms total between Isabella and Sycamore Streets, the distance being approximately 10 000 feet. The Springfield Railway Co.'s tracks on Main will be for the most part 60-pound rails, having a resistance of 0.0037 ohms for the entire distance between Isabella and Sycamore.

The current of the Ohio Electric Co. which may be considered as originating at D east of Lagonda Avenue, amounts to approximately 400 amperes on the average. The current of the Springfield Electric Railway line coming from west of Lagonda is during the average day load of the order of about 1000 amperes. This is, of course, distributed over the entire city, but for purposes of illustrating the advantage of the interconnection of the two railway track systems, we may assume that a load of 500 amperes concentrated on west Main Street in the vicinity of Western Avenue. This will of course not represent an actual condition, but would give a total drop on the Main Street tracks to the power houses which is approximately equal to that produced by the distributed load which actually exists there. Under these assumptions the drop on the Ohio Electric tracks along North Street between D and the Ohio Electric power house at B would be the current multiplied by the resistance which equals 400 times 0.024 = 9.6 volts, the gradient being from east to west. The drop on the Springfield Railway tracks along Main between C and the power house A would be 500 times 0.037 = 18.5 volts. Since these drops are in opposite directions it will be impossible to prevent large differences of potential between the tracks on Main and North Streets. If, for instance, rails at both power houses are at zero potential, then the Ohio Electric tracks near Columbia and North will be 9.6 volts positive to the rails of the Springfield Railway Co., giving rise to large leakage of current through the earth between the two systems which would cause serious injury to the pipes. Further, the potential between the Springfield Railway tracks west of Main and the tracks on North Street near the Ohio Electric power house would be about 18.5 volts, producing an even more serious condition than the former. The distance between the tracks here being only about 1000 feet, the potential gradient will be seen to be enormous, and it would inevitably result in serious

injury to the pipes in that locality. If, however, the tracks are tied together at all streets on which cross tracks now exist, namely, at Isabella and Western, Wittenberg, Limestone, Sycamore, and Lagonda the current from the two directions would divide between the tracks and since they would flow in opposite directions, the resultant current would be the difference between the two, or only about 100 amperes, which would be directed eastward and toward the Springfield Railway Co.'s power house.

The combined resistance of the two tracks in parallel is only 0.015 ohm, giving a drop of 1.5 volts over the entire 10 000 feet. It would thus be impossible to produce any large difference of potential between any two points on the tracks. Further, the drop would in this case be in the same direction on both tracks instead of the opposite direction as would be the case if the tracks were not interconnected, so that they would be almost absolutely at the same potential throughout their entire length. It will thus be seen that the voltage conditions will be enormously improved by tying the tracks together, and what would otherwise be a very dangerous condition along the entire line between the two power houses would be converted into a condition of comparative safety. It is thus clearly seen that tying the tracks together at various points amounts, in effect, to an interchange of current on the negative side between the two power houses. The Springfield Railway Co.'s power house would then intercept the Ohio Electric's current coming from the east beyond Lagonda, while the Ohio Electric Co.'s station would take a corresponding amount of current from the Springfield Railway tracks in the western part of the city, only the difference between the Ohio Electric load and the Springfield Railway load being taken from the west back to the Springfield Railway power house.

In addition to the improvements in the electrolysis conditions above noted, there will also be a large saving in power. With the tracks separated the loss on the Ohio Electric tracks between Lagonda and Isabella will be the current multiplied by the voltage drop, or 400 times 9.6 = 3840 watts = 3.84 kw, and on the basis of an 18-hour day this gives a total of about 25 000 kw-hr per year. On the Springfield Railway tracks between Lagonda and Western Avenue the loss would be 500 times 18.5 = 9250 watts = 9.25 kw,

giving a total annual loss of 60 000 kw-hr. The total loss on both tracks would therefore be 85 000 kw-hr per year. At 1 cent per kilowatt hour this is $850 per year. As seen above, however, if the tracks are tied together, the average current in this same section is reduced to approximately 100 amperes, and the total drop to only 1½ volts, hence the loss is but 150 watts, giving an annual loss of 972 kw-hr per year, which at 1 cent per kw-hr would be worth but $9.72. The saving, therefore, resulting from tying the tracks together would be over $840 per year, the capitalized value of which would at least be $14 000. It thus appears that the interconnection of the tracks at the various points on which cross lines already exist would have a very large monetary value to both companies, and would be very desirable from an economic standpoint regardless of any consideration of electrolysis protection. When, also, we consider the great improvement in voltage conditions that would accompany such interconnection, it is evident that such interconnection of the tracks is the only wise course to pursue.

The electrical measurements obtained by the engineers of this Bureau show that at certain places at least, such interconnection does not now exist, as at Columbia and North Streets, for example, where large differences of potential were found to exist between the tracks on the Ohio Electric and Springfield Railway lines at the crossing. In view of the considerations pointed out above it is obvious that this condition should be corrected as soon as practicable. We have also been informed that one of the railway companies contemplates insulating the tracks of the two systems from each other at all crossings. As pointed out above this would greatly increase the danger of electrolysis troubles due to stray currents as well as materially increase the operating cost because of the increased power loss, and we very strongly urge that this plan to isolate the two systems be not carried out, but on the contrary, special precautions should be taken to insure thorough bonding between the tracks of the two systems at all intersections.

3. CROSS TYING OF TRACKS ON EAST MAIN AND HIGH STREETS

Another matter of importance in addition to the installation of properly designed insulated feeder system is the placing of a proper crosstie between the tracks on east Main and east High

Streets at or in the vicinity of Sycamore or Lagonda Avenue. The reason for this is that these tracks run approximately parallel and quite close together for a long distance without any cross lines to produce an electric connection between them. It will be evident that the potential difference between the two lines at adjacent points will be due to differences in the drop along the two tracks extending eastward from Limestone Street, at which point they are practically tied together by the rails on the Limestone Street line. Thus, if the drop along Columbia between Lagonda and Limestone should be 10 volts and the drop on east Main Street over the same distance should be, say, 5 volts, then the potential drops between the tracks at Lagonda would be 5 volts, and since the distance here is very short this would give rise to a very high potential gradient between the two lines which would be sufficient to cause dangerous leakage of current into the earth, and consequently, serious damage to the pipes. In order to overcome this difficulty a heavy copper cable should connect the two lines on High and Main Streets to serve as an equalizer and prevent any large differences of potential of this sort from arising.

4. NEGATIVE FEEDER SYSTEMS

The above recommendations while important and necessary to the securing of satisfactory immunity from electrolysis troubles must nevertheless be considered as secondary in importance to the installation of a properly designed and maintained system of insulated negative feeders connecting the negative bus bar to various points in the rail return. The system of negative feeders already installed is shown in Chart II. By reference to this chart it will be seen that this system comprises a feeder running from the power house at Sycamore and Warder up to the corner of Main and Limestone, at which point it branches and rebranches and ties to the tracks at a number of points on west Main, west High, west Pleasant, and South Limestone Streets, thus draining the tracks in a large part of the center of the city. Another feeder extends from the power house along Warder and College Avenues to the corner of Limestone and College. A third feeder runs south along Sycamore to east High Street, thence east and taps to the rails at East and High and at Glenn and High, also

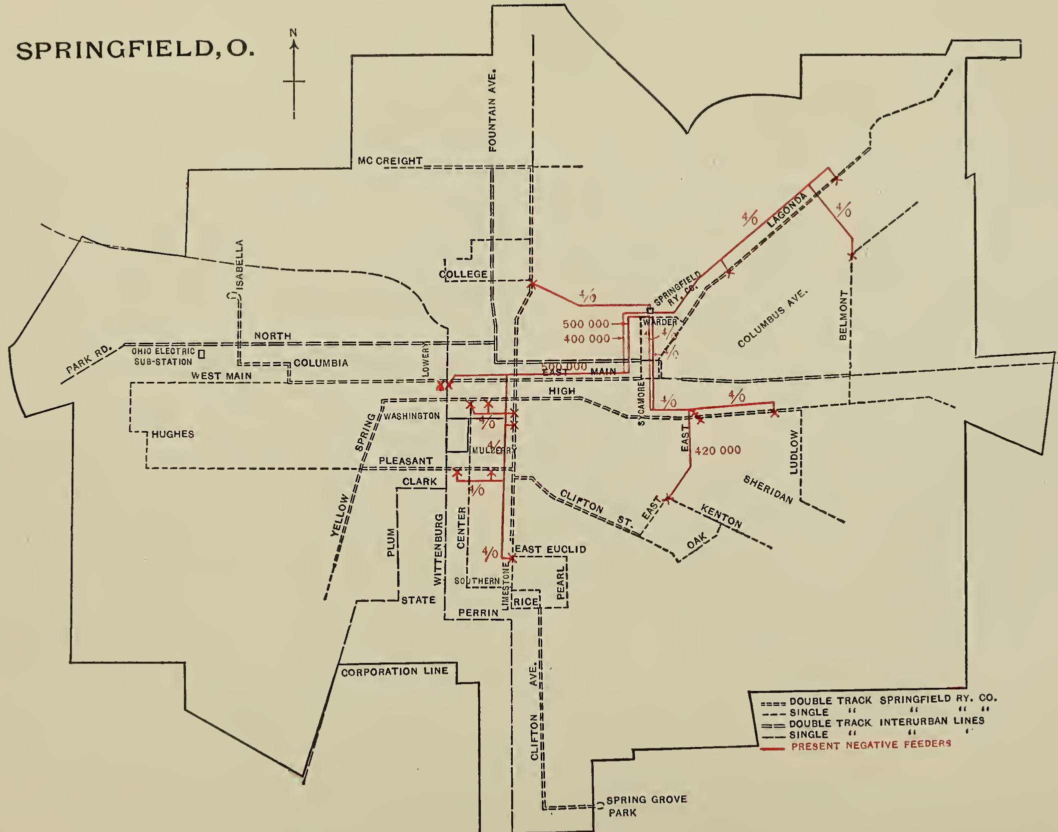

Chart No. II.—*Present negative feeder system*

south on East to Kenton Street. A fourth feeder runs along Warder and Lagonda Avenue, thence along Lagonda to James Street, thence along James to Columbia Avenue with taps to rails at Pauline and Lagonda, James and Lagonda, and James and Columbia Avenue. As at present constituted, this feeder system, while undoubtedly greatly improving electrolysis conditions, is not altogether satisfactory for several reasons. In the first place the arrangement of the feeders is such that comparatively little current is taken from the feeders running east from the power house on Lagonda and east High Streets, while a relatively large amount of current is taken from the feeders running to Limestone and beyond. As a result of this the direction of current flow in the rails on Columbia and east Main and east High between Sycamore and Limestone Streets is actually away from the power house. This tends to produce the lowest potential up in the heart of the city, and causes a complete loss of the conductivity of the double track lines on these streets, which could be utilized if the feeder system were so proportioned as to cause a considerable amount of current to flow eastward on those streets and be taken off in the region of Sycamore Street.

A redesign of the cables so as to take less current from the territory surrounding Limestone Street and a greater proportion from feeders draining the region to the east of Sycamore Street would at once produce better potential conditions and likewise give rise to much greater economy because of the more direct route by which the current would be returned to the power house. Another disadvantage of the present feeder system is the relatively large potential drop which now occurs on these feeders, thus giving rise to a large energy loss. As will be shown later by a detailed calculation, a redistribution of the feeder copper would result in large economies in this direction. A further defect growing out of the high drop of potential of the feeders is the fact that the potential difference between the different points at which the feeders are connected to the tracks depends on the differences in the potential drop in the various feeders themselves. Since the load is constantly fluctuating from point to point the drop on these feeders will necessarily change, so that it is impossible to maintain the terminal points of the various feeders always at the same potential.

It will be evident that a given shifting of load producing a certain percentage variation in the drop on an individual feeder, will cause a greater potential difference between termini of the feeders if the total drop on the feeders is large, than the same percentage variation of a load would produce if the total drop on the feeders were relatively small. For this reason a redistribution of the feeder copper such as to reduce considerably the total drop on the negative feeder would result indirectly in much smaller potential differences between those points on the track to which the feeders are connected, and consequently the earth gradients throughout the city would be much smaller, and electrolysis correspondingly improved.

In order to show how the system can be redesigned to overcome these objections, we have worked out a detailed plan for changing the present negative feeder system in such a manner as to secure at once adequate protection of the pipe systems and the greatest economy in installation and operation. This plan of reorganizing the negative feeder system is outlined in detail below. A complete plan of the proposed feeder system is shown in Chart III, showing the size and location of the feeders required and the points at which they should be tapped to the rails. We have also given a careful estimate of the cost of converting the present system into the system proposed, together with an estimate of the economies resulting therefrom. It will be found that while the proposed changes contemplate the expenditure of about $4900, the change will be accompanied by certain operating economies which will result in a saving sufficient to pay large returns on the cost of making the necessary changes.

In making the calculations for the negative feeder system it was necessary first to secure data as to the average distribution of load in the track network. In order to do this the car schedule of the entire system was obtained from the Springfield Railway Co., and from this schedule the average car distribution was laid out on a map of the railway system, as shown in Chart III. The average current per car is found to be very close to 40 amperes, and this value has been used in all calculations. In making the calculations the normal average load car distribution is determined from the car schedule as represented in Chart III. A careful study of the load and track layout was made and the approximate dis-

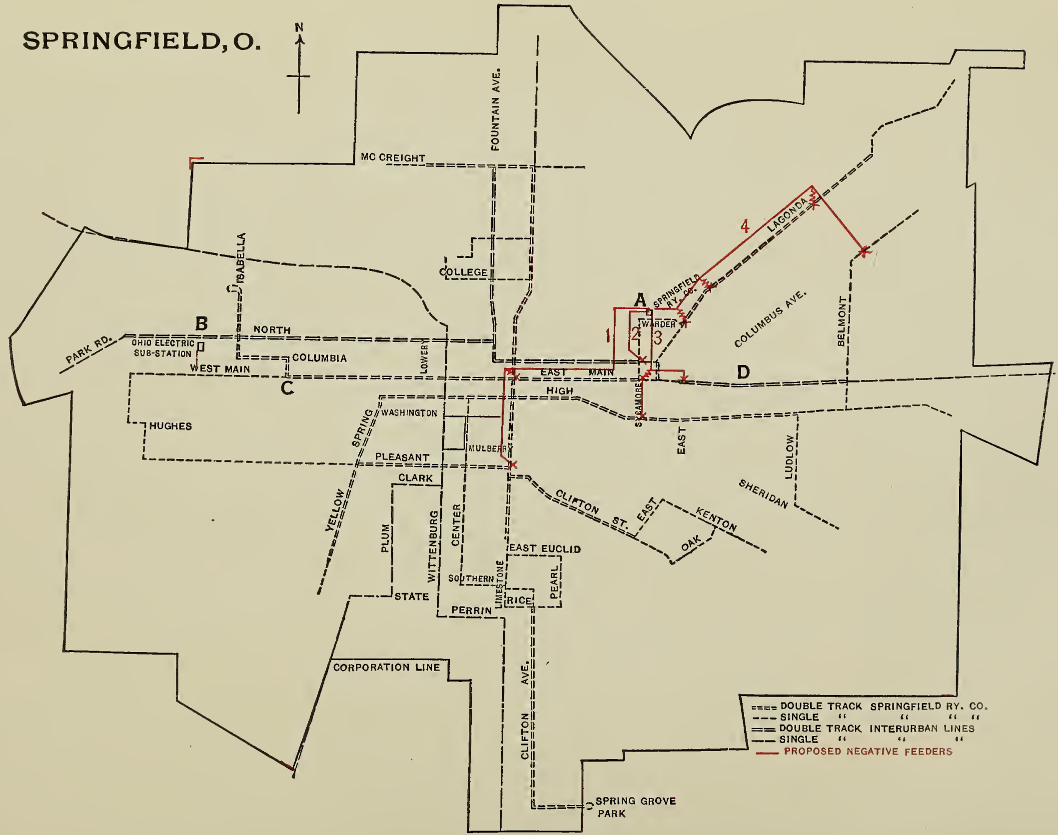

Chart No. III.—*Proposed negative feeder system*

tribution of the current in the rails determined, beginning in the outlying portions and gradually tracing the current distribution as the station was approached. Where it was found that the current density at any point was such as to give a potential greater than one-half volt per 1000 feet, a feeder of suitable size was connected to the rails to carry off the excess current. In this way the potential gradient throughout the entire negative return of the railway is maintained below one-half volt per 1000 feet. This is but a small fraction of the potential gradient existing in the rails prior to the installation of any negative feeder system, and will of course give rise to a corresponding reduction in electrolysis troubles. It is believed that this figure is sufficiently low to practically eliminate any serious electrolysis trouble. The result of the calculations shows that a total of four feeders are required, together with a suitable number of taps as hereinafter described. These feeders and their routing are described in detail below and a condensed statement of all the essential data in regard to them is given in Table I.

TABLE 1

Insulated Negative Feeders for Springfield Railway Co.

	Location	Length, 1	Current, amp	Cross section, M. C. M.	Potent drop, volts	Loss, KW	Copper, weight	Copper, added.
1	Limestone, Pleasant to Main..	2440	120	0.605	4.84	0.581	4470	2165
	Main-Limestone to power house	5520	200	1.000	11.04	2.208	16 720	8360
Tap	At Limestone and Main		80		3.67	.294		
2	Columbia to power house, Sycamore	1700	310	.413	12.72	3.9	2130	2130
Tie	Sycamore-High to Main	1050	240	3.410	.74	.178	10 850	9540
3	Sycamore Main to power house.	2220	380	.837	11.04	4.6	5640	2750
	Main-East to Sycamore	1160	140	.605	2.69	.377	2130	820
Tap	Main and Sycamore		300		1.95	.585		
4	James-Lagonda	5510	40	.212	10.4	.416	3540	0
Tap	Lagonda and James		40		6.25	.250		
4	Nelson-Lagonda to Warder	1270	80	.317	3.20	.256	1220	406
Tap	Lagonda and Warder		130		9.24	1.20		
Con	Warder-Lagonda to power house	1060	210	.794	2.80	.589	2560	1870
	Total					15.434	49 260	28 041

Annual energy loss = 101 200 kw-hours.
Annual energy loss = $1012.00
Copper value = $12 315.00
Annual interest on copper = $985.20.
Annual saving in energy loss = $2805.00

Feeder No. 1.—This feeder extends from the negative bus at the Springfield Railway Co.'s power house to the corner of Main and Limestone Avenue; throughout this length it has a cross section of 1 000 000 circular mils. At this point a suitably designed resistance tap connects the feeder to the rails, taking off 80 amperes. The feeder then continues south on Limestone Street to the corner of Pleasant, the cross section of this portion of the feeder being 605 000 circular mils. At Pleasant a current of 120 amperes is taken from the tracks, the total drop of potential on this feeder between Pleasant and Main is 4.48 volts (calculated), and between Main and Limestone and power house the drop is 11.04 volts, giving a total potential drop of 15.52 volts, and a total power loss during average conditions of load of 2.8 kw. The total weight of copper in this feeder will be 21 190 pounds, but since there is already a large amount of copper installed on this route the additional copper required will be but 10 525 pounds.

Feeder No. 2.—This feeder runs from the power house to the corner of Sycamore and Columbia, a distance of about 1700 feet. It here taps to the rails, taking off an average of about 310 amperes; the cross section required is calculated at 413 000 circular mils, giving a drop of 12.72 volts, and an average power loss of 3.9 kw. The total weight of copper required is 2130 pounds.

Cross tie between High and Main at Sycamore Street.—This is the cross tie referred to above designed to prevent large differences of potential arising between the tracks on east Main and east High. Its length will be about 1050 feet and the cross section 3 410 000 circular mils. It is depended upon to carry 240 amperes average from east High Street, which would give a potential drop of 0.74 volts, and an average power loss of 0.1780 kw. The total copper required is 10 850 pounds.

Feeder No. 3—This runs from the power house to the corner of Sycamore and Main, which section has a cross section of 837 000 circular mils. At Sycamore and Main the feeder is tapped to the rails through a resistance tap designed to take off 300 amperes. The feeder also continues east on Main Street to Lincoln Street, where it is tied directly to the rails. This latter section has a cross section of 605 000 circular mils and is designed to carry 140 amperes. The length of this latter section is about 1160 feet

and the length of the section between the power house and Sycamore and Main is about 2220 feet. The total weight of the copper required will be 2130 and 5640 pounds, respectively, for the two feeders, giving a total of 7770 pounds, of which a considerable portion is already in place. The total power loss of this feeder, including the loss on the tap at Main and Sycamore, will average about 5.5 kw.

Feeder No. 4.—This feeder runs from the power house along Warder to Lagonda, thence along Lagonda to James, thence along James to Columbia. It will be seen that the route of this feeder is identical with that already in place, and the cross section is the same from the terminus at James and Columbia to the corner of Lagonda and Nelson. The current carried on this cable is small and the energy loss only about 0.4 kw. There is a resistance tap at Lagonda and James designed to take about 40 amperes from the rails at a potential drop of 6.25 volts, giving a power loss of 0.25 kw. From Nelson to Warder the cross section of the feeder is 317 000 circular mils, thus requiring the addition of 406 pounds of copper in this section. A tap at Lagonda and Warder designed to take 130 amperes from the track has a drop of 9.24 volts and a power loss of 1.2 kw. From Lagonda and Warder to the power house the current carried is 210 amperes, requiring a cross section of 794 000 circular mils, and the distance 1060 feet, which requires a total of 2560 pounds in this section, or an addition of 1870 pounds to the copper already there.

Summing up, we find that the proposed feeder system would require a total of 49 260 pounds of copper, of which, however, 21 220 pounds are already in place. The total power loss as seen from Table 1 is 15.4 kw, which gives an annual loss of 101 200 kw-hr, having a value at 1 cent per kw-hr, or $1012 per year. In order to determine the cost of the system, however, we must deduct the value of copper which can be removed in making the change, and also determine the saving in power that results. A study of the proposed layout shows that the following copper that is now in place can be removed. The feeder running from the power house to College and Limestone, on Main from Limestone to Lowry, on High from Limestone to Center, on Pleasant from Limestone to Center, on Limestone south of Pleasant, and a short section on

east High street. All of these are 4/0 cables and have a total weight aggregating 8590. There is also a section on East Street of 420 000 circular mils weighing 3040 which is not required under the proposed plan. This gives a total of 11 630 pounds of copper to be removed. The value of this is figured at 18 cents a pound after allowing for the cost of removal, which gives a value of $2095 as the value of the copper recovered. From Table 1 it is seen that the total copper required to be added is 28 040 pounds, the cost of which estimated at 25 cents per pound is $7010. The net initial investment required would therefore be $7010, minus $2095 = $4915. The annual cost of the copper added reckoning 8 per cent on the initial investment amounts, therefore, to $393. From this annual cost, however, we must deduct the annual value of the power saved by changing to the proposed installation. To determine this we must calculate the power loss in the present system of negative feeders. Measurements of the total drops of potential on these feeders shows that the average drop on all the feeders during the average day load amounts to about 44.3 volts, and since all the current returns over these feeders under the present system the average power loss is equal to the average drop on the cables multiplied by the average current, which gives 44.3 times 1310 times $10^{-3} = 58.1$ kw. This gives an annual loss of 381 700 kw-hr, which at 1 cent per kw-hr has an annual value of $3817. It was shown above that the annual energy loss under the proposed system would amount to $1012, so that the net saving in power loss reaches $2805 per year. Deducting from this saving in power the above figure of $393, which was the annual cost of the necessary changes in the copper feeders, we get a net saving of $2412 per year under the proposed plan. Another way of looking at it is that the total saving in power amounting to $2805 per year yields 57 per cent on the total cost of reconstructing the negative feeder system. It appears, therefore, that from the standpoint of economy alone it is highly important to make the changes recommended. It will be evident also that since the total drop on the feeders, as shown by Table 1, has been reduced to not more than one-fourth of the drop under present conditions, any fluctuations in load distribution will produce very much smaller potential differences between the termini of the feeders

than at present and consequently the tendency for high potential gradients in the earth will be very greatly reduced, and electrolysis conditions through the city correspondingly improved.

It will be noted that in the proposed plan there is no direct connection between the rails and the negative bus out of the power house. Such connection is omitted primarily for the reason that this district is in low ground that is likely to be comparatively damp, and consequently of low resistance, so that to make this the most positive part of the system as would be the case if any considerable current were taken off at the power house, would be to throw the positive area in a region where it would do the greatest amount of damage. On the other hand, by removing the power-house connection the positive areas are thrown out at the termini of the feeders which are located on relatively high ground, where owing chiefly to lower moisture content, the average resistance of the soils will be much higher than down near the power house, so that the given difference of the potential between pipes and rails would be much less serious. This is an important point which should always be considered in the design of insulated negative feeder systems.

In considering the need for negative feeder system at the Ohio electric station, it is found that owing to the comparatively small current taken from the tracks east of the substation the tracks alone will have ample carrying capacity up to the corner of Isabella and North Streets, providing the tracks of the two railway systems are interconnected, as recommended in the foregoing. In order, however, to facilitate the interchange of current on the negative side and to reduce the potential gradient in the tracks between Isabella and North, and the substation, it is very desirable to run a short feeder directly across South from the Ohio electric substation to the Springfield Railway tracks on west Main Street. This feeder will need to carry only about 120 amperes, so that the section should be about 400 000 circular mills. The distance would be about 950 feet, giving a weight of 1150 pounds of copper. In order to make proper use of this and to prevent too large gradients in the tracks on North Street, it would be necessary to install a very low resistance tap between the negative bus bar and the North Street tracks at the power house, such as would give a

drop of potential of about 0.85 volts between the tracks and bus bar. This would probably not require much additional resistance above that possessed by the tap already in use. The total cost of this feeder installed would not exceed about $285.

SUMMARY.

Reviewing the recommendations in the foregoing report it will be seen from the discussion of the various proposed methods of electrolysis mitigation that those methods which are intended to be applied to the pipe system are regarded as unsatisfactory in general, and particularly so for conditions as they exist in Springfield. This is the more emphasized by the fact that there are in the pipe systems at Springfield, especially the gas system, a considerable number of insulating joints, the gas company, we are informed, having several hundred Dresser couplings scattered throughout its system.

So long as these insulated couplings are in place the application of negative feeders to either the gas pipes or the water pipes, or to both, would prove disastrous to the gas system in the vicinity of these insulating couplings. On the other hand, if the system of insulated negative feeders be applied to the tracks as recommended in the report so that the potential difference between different parts of the networks are reduced to the comparatively low value, the presence of these insulating joints would be decidedly beneficial, since they would tend still further to reduce the current flow in the pipes, while the potential gradients would be so small that dangerous potential drops across the insulating joints could not arise. The life and property hazard would also be increased by the installation of a system of feeders connected to the pipes, because of the dangers from fires and explosions already pointed out in this report.

After a full consideration of the relative merits of all the different systems available, we strongly recommend that the insulated negative feeder system applied to tracks be adopted as the primary means of electrolysis mitigation in the city of Springfield, and the system hereinabove proposed and worked out in detail is believed to be entirely adequate to take care of the situation for some time

to come, and can readily be modified and extended to take care of any situation that may arise as the system grows.

It is further recommended that the joints in all the railway systems operating in the city of Springfield be tested at intervals not exceeding six months or a year, and all joints showing resistances exceeding that of 3 feet of rail should be immediately rebonded so as to maintain perfect continuity of the tracks throughout the city.

It is also of very great importance to have the railway tracks of the Ohio Electric Co. and the Springfield Railway Co. interconnected electrically at all crossings, both for the sake of economy of operation and for the safety of the pipe system. To neglect this interconnection, or to deliberately insulate the two systems from each other, would invite certain disaster to the underground pipes.

It appears from the calculations set forth above that the proposed system of insulated track feeder will not only greatly improve voltage conditions throughout the entire negative return, but will also bring about large economies in power which will pay large returns on the small investment required for putting the proposed plan into effect. As compared with the arrangement of insulated track feeders that is now in service, the proposed system would give considerably smaller drop on the negative return, which in turn would give a higher average voltage on the cars with consequent improvement in the car service and car lighting.

We are confident that this system if properly installed and maintained will prove to be the most effective means of affording permanent relief to the pipe owning companies of Springfield from damage due to stray currents from the street railways.

WASHINGTON, June 19, 1913.

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